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Horizontal Distribution of Illuminance with Reference to Window Wall Ratio (WWR) in Office Buildings in Hot and Dry Climate, Case of Iran, Tehran

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Abstract. The Issue of daylight inclusion in the office buildings has got the significant importance in the recent years. Using this light, dependence on artificial lighting sources can be reduced which results in the energy efficiency. This study aims to determine the optimal Window Wall Ratios in the office buildings of Tehran to take the advantage of daylight abundance regarding the climatic features without making the designers involved with the complicated calculations. All the research analyses have been done based on the window models comparison through the computational simulations. After the primary analyses, the models were developed and put to the test again. The study shows that among from all the tested models, an optimal WWR range for the office buildings of Tehran can be proposed.

Introduction

Daylighting in Buildings and Importance of Window Wall Ratio: Energy use in buildings accounts for a large percentage of total energy consumption worldwide, which leads to a great amount of CO2 emission to atmosphere. European studies on energy consumption show buildings are responsible for 40% of energy use and 30% of CO2 emission [1].The most obvious vehicle for energy savings in buildings is in exploiting the most abundant source of light available to us – daylight [2]. In the offices of Tehran, artificial light is considered as the main contributor to the visual environment, even though there is an abundance of daylight during that part of the day known as ‘office hours’. Therefore, by reducing reliance on artificial lighting, daylight can be an effective means of saving on lighting energy [3], especially in Iran that according to Tavanir (Iran Power Generation, Transmission & Distribution Management Co), 25% of all electricity consumption of an office building is on artificial lighting [4]. Not only does daylight allow one to save on energy consumption, but studies show that people actually perform better when exposed to daylight [5]. Among the other advantages of daylight are physiological as well as psychological benefits for users [6]. So, strategies for more daylight inclusion are needed for office interiors in context of any city which has a growing demand on electricity such as Tehran. An important aspect of effective daylight strategy is the performance of the window (the transparent part of building envelope) in permitting daylight entry. The form, location and dimensions of windows are rarely determined according to the knowledge but usually to the preference of designer [7]. This study aims to provide the designers with an optimal range for the window design, without making them involved with the complicated computational calculations.

2. Theoretical Framework and Model Description

Glazed windows are becoming an important component of contemporary architecture [8]. Since the windows have a considerable impact on the thermal performance of the building envelope, they can greatly affect the building energy performance. Study reported by Jinghua Yu showed that heat gain through the exterior window accounts for 25-28% of the total heat gain, adding to the infiltration. It is up to 40 % in hot summer and cold winter zone. Therefore, the proper design of windows can greatly reduce the energy consumption in buildings [9]. The designer has a number of choices in designing the windows, including the location of window, the form of window, the material of window components and the window to wall ratio (WWR) that is the percentage of transparency to solidity.

2.1. Applied Range of Daylight Illuminance: the rational ranges for the daylight illuminance, determined by Azza Nabil include the following items:

• Daylight illuminances less than 100 lux are generally considered insufficient either to be the sole source of illumination or to contribute significantly to artificial lighting.

• Daylight illuminances in the range 100 lux to 500 lux are considered effective either as the sole source of illumination or in conjunction with artificial lighting.

• Daylight illuminances in the range 500 lux to 2000 lux are often perceived either as desirable or at least tolerable.

• Daylight illuminances higher than 2000 lux are likely to produce visual or thermal discomfort or both [10].

Although for the purpose of our analysis, three ranges is applied: daylight illuminances less than 500 lux, in the range 500 lux to 2000 lux and higher than 2000 lux. Moreover, in this article, the ratio of the positive area to the total area in the offices is calculated and is defined as 'daylight efficient ratio'. So, if the work plane be set in such area, the artificial lighting is not required.

2.2. Climatic Features Affecting the Analysis Process: Tehran, where the model is originally developed, is located between mountain and desert in the southern slope of Alborz with the latitude of 35.7° and 51.3°; it results in a hot and dry climate. Based on the meteorological statistics, reported by Mehrabad Weather Station, the sky of Tehran during a year is 64% clear, 27% partly-cloudy and 9% cloudy [11]. Considering the significant percentage of the clear sky mode, all calculations are based on the condition that the solar radiation is direct and the sky is cloudless.

2.3. Physical Scale of Model: All the Calculations are done for an office room with width of 4m, depth of 6m and height of 2.70m. The rooms' interior walls are covered with the plaster. A work plane of 0.9m is used as this is a common practice for the office buildings. Ten different window models are tested on the southern front of the room. Each window extends %5 in dimensions comparing with the previous one. So the research models are 10 windows with WWR %15 to %60. The square windows on the wall vertical axis are tested. In smaller windows, the window banisters are set on the work plane, but in larger windows, due to the ceiling height, they are set below the work plane. Another variable to be considered for each window model is the solar shading as a horizontal plane above the window. The optimal shading for each window is calculated by means of Ecotect and Radiance software.

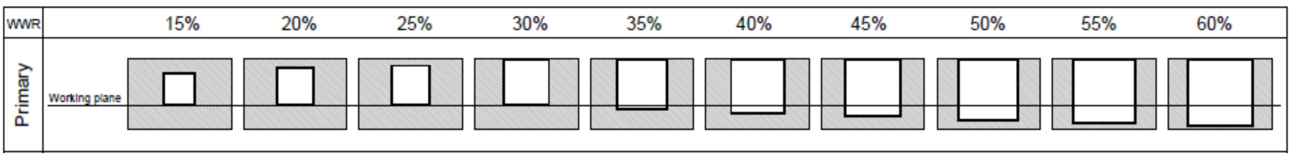

Fig. 1 Configuration of models

Table1. The details of window's properties

Characteristics	Quantity
Sky design illuminance	8259 lux
Window clearness Average	Average (x 0.9)
Window type	Double Glazed Alum-Frame
Visible Transmittance	0.639
Refractive index of glass	1.74

3. Inference Mechanism

3-1- Research Goals: determining the optimal Window to Wall Ratios in the office buildings of Tehran to take the advantage of daylight abundance, regarding the climatic features.

3.2. Research Questions: What relation there is between different Window Wall Ratios (WWR) and amount of illuminance in the office buildings in the climate of Tehran? What are the optimal Window Wall Ratios in the office buildings in the climate of Tehran?

3-3- Research Case-study: Tehran, the capital of Iran and the center of official buildings is selected as the research case-study.

4. Discussion

To achieve the research goals, ten window models with square form are analyzed. Based on the average monthly illuminances, the increase of WWR entails the increase of the area more than 2000 lux and the area in the range 500 lux to 2000 lux. Moreover, the increase of WWR entails the decrease of the area less than 500 lux. The monthly illuminance comparison shows that the area more than 2000 lux and in the range 500 to 2000 lux in the summer months are smaller than the winter months. Also, the area less than 500 lux in summer months is smaller than the winter months. About the models with WWR %15, %20 and %25, WWR variations entail the illuminance unusual changes (Fig. 2). For the models with WWR %30 and %35, the area higher than 2000 lux and the area in the range 500 lux to 2000 lux are equal, approximately. About the models with WWR more than %35, the area less than 500 Lux is diminished and two other areas are extended. About the models with WWR %55 and %60, the extension of area higher than 2000 Lux is more than %10 which results in the illuminance undesirable distributions (Fig. 3). Since about the models with WWR %30 to %60, part of window is below the work plane, WWR variations in such models entail the illuminance slight changes. To study the WWR effects on the work plane illuminance, the models with the windows totally above the work plane are taken into consideration and to set the windows above the work plane, the Rectangular window form are analyzed at the next stage (Fig. 4).

4.1. The Developed Models Analyses: at this stage, the rectangular windows with the fixed height of 1.62 meters are taken into consideration. Comparing with the primary models, setting the windows above the work plane entail the extension of the area more than 2000 lux and the diminish of the area in the range 500 lux to 2000 lux, but the area less than 500 lux is not encountered with the considerable changes. Although the extension of the area more than 2000 lux is the result of lightening the room corners on the window side, such corners in the primary models are too small to set the window plane. In other words, comparing the areas more than 2000 Lux in the primary and developed models shows that such area in both models gets the equal penetration depth. The illuminance distribution analysis of the room depth shows that the area more than 2000 lux is away from the window less than 2 meters, while the room depth illuminance of the developed model increases. One of the factors which is affected by the WWR's increase is the direct solar gains; so that the increase of WWR entails the increase of direct solar gains and ultimately the interior temperature. Considering the optimal shading for each window, the most direct solar gains is in the cold months and the least direct solar gains is in the hot months (Fig. 5, 6, 7, 8).

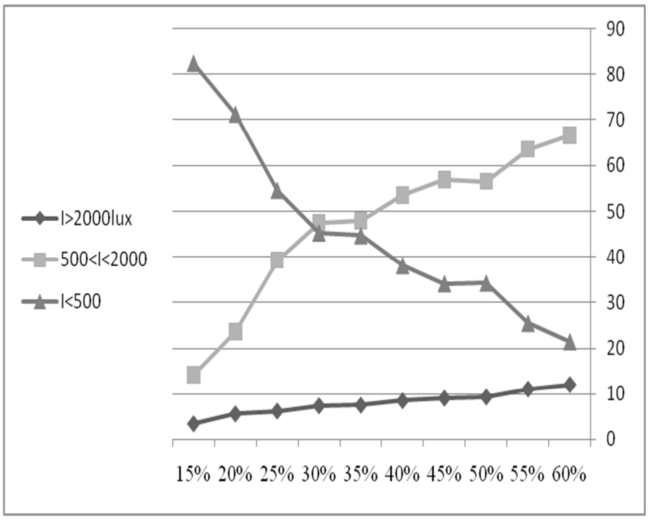

Fig. 2 The annual average of three defined areas for all the models

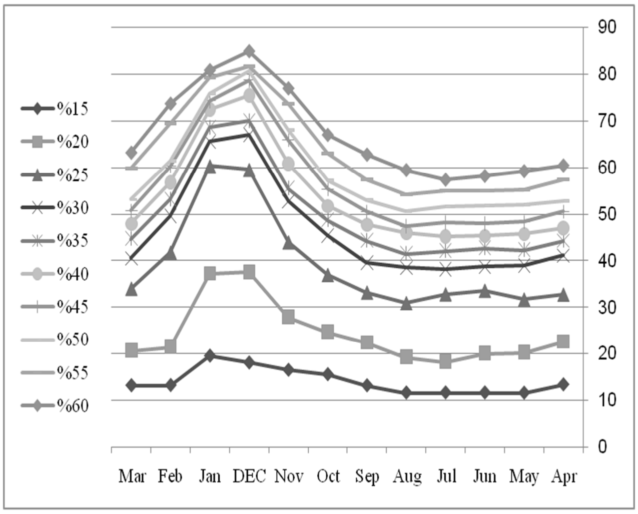

***Fig. 3** The monthly average of 'daylight efficient ratio'*

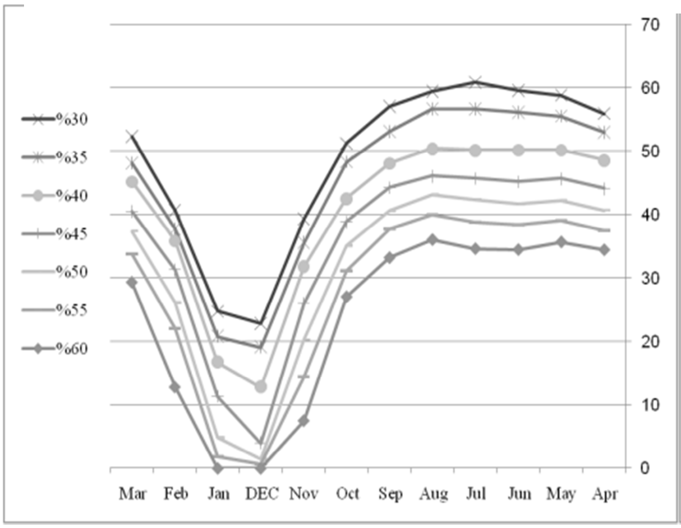

***Fig. 5** The area less than 500 lux in the developed models*

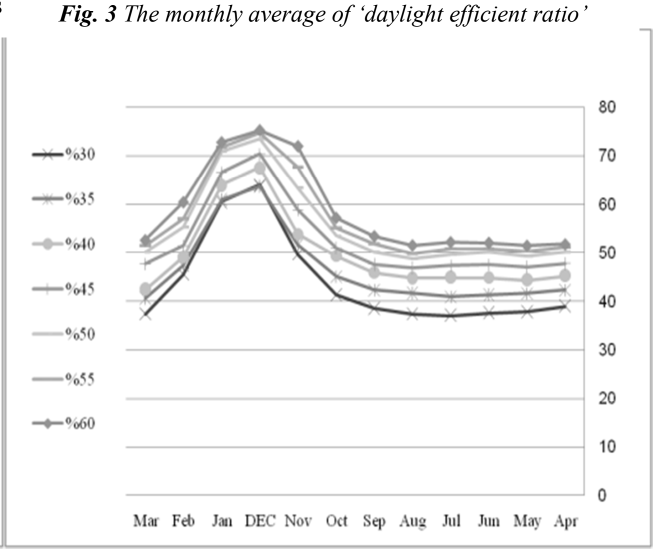

***Fig. 6** 'Daylight efficient ratio' in the developed models*

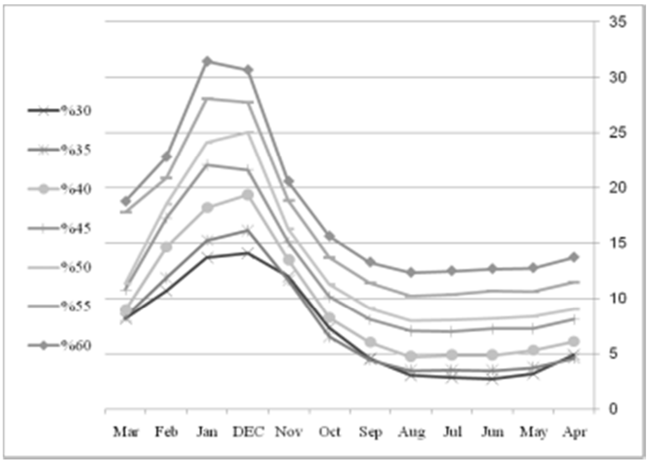

***Fig. 7** The horizontal distribution comparison in developed models*

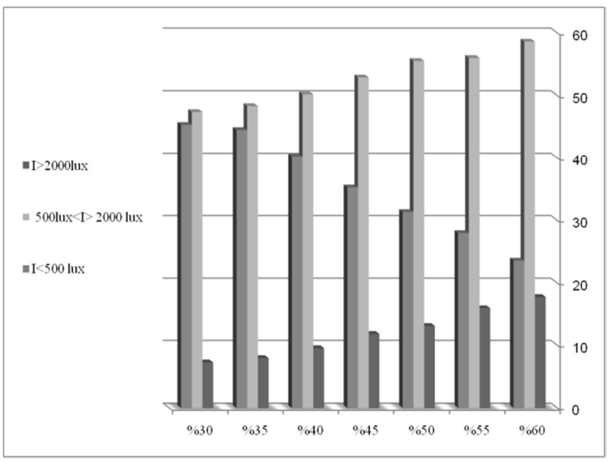

***Fig. 8** The area more than 2000 lux in developed models*

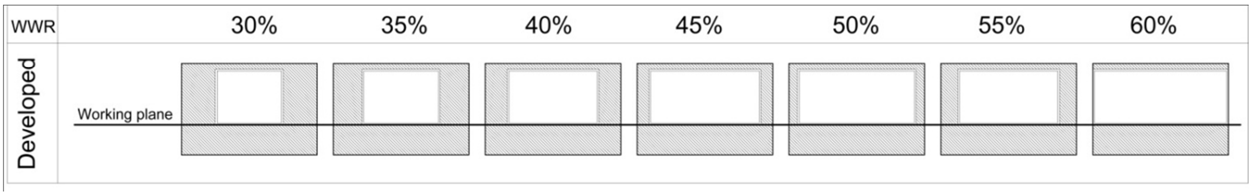

Fig. 4 *Configuration of developed models*

5. Conclusion

Based on the comprehensive analyses, about the models with WWR %15, %20 and %25, in exchange for %5 increase in WWR, approximately %10 is added to 'daylight efficient ratio' and about the models with WWR %30 and %60, just %2 is added to 'daylight efficient ratio'. About the models with WWR %30 and %35, the areas in the range 500 lux to 2000 lux and less than 500 lux are approximately equal. Moreover, the area less than 2000 lux is smaller than other ones. About the models with WWR more than %35, although the area less than 500 lux is diminished as a desirable point, but the area in the range 500 lux to 2000 lux extends extremely; so that about the models with WWR more than %45, the area higher than 2000 lux includes more than %10 of the work plane, while such extension is not ideal for the office furniture. Although, considering the direct solar gains, the models with less WWR seem to be the most appropriate ones, but because of the priority of the average or moderate options due to the unforeseen or unsettled variables related to the extreme options, the most appropriate options are WWR %30, %35 and %40.

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